Comment on "Point-Contact Study of Fast and Slow Two-Level Fluctuators in Metallic Glasses"

In a beautiful recent experiment on mechanically controlled break junctions made from metallic glasses [1], Keijsers, Shklyarevskii, and van Kempen (KSK) found a zero-bias anomaly (ZBA) in the differential conductance that switched between two or more values (switching times >1 s). The V dependence of the fluctuation amplitude $\Delta G(V) = |G - G'|$, shown in Fig. 1 for two of KSK's samples, implies that this is not simply a standard telegraph-noise-like signal superimposed on a ZBA, since then ΔG would be constant. KSK attributed the ZBA to *fast* two-level systems (TLSs) in the junction, and its telegraph-like fluctuations to the modulation of some fast TLSs' parameters, induced by short-ranged interactions with nearby, *slowly* switching two-state systems.

KSK found that if a *distribution* of TLS parameters is assumed, the ZBA's overall shape is consistent with both the theories of Kozub and Kulik (KK) [2] and Vladár and Zawadowski (VZ) [3–5] for the TLS-electron interaction. In this Comment we point out that the two theories make different predictions, however, for the shape of $\Delta G(V)$, since it is so small ($\Delta G_{\max} < e^2/h$ for all samples) that the parameters of *only one or two* TLSs (labeled by $i = 1, 2$ below) seem to be modulated by slow fluctuators. Since the TLS-electron couplings depend strongly only on the interwell distance, but changes in the environment mainly alter the well depths, the parameters modulated most strongly will be the TLSs' asymmetry energies E_i. Thus, one should be able to fit $\Delta G(V)$ assuming induced telegraph fluctuations, $E_i \Leftrightarrow E_i'$, for only a few TLSs.

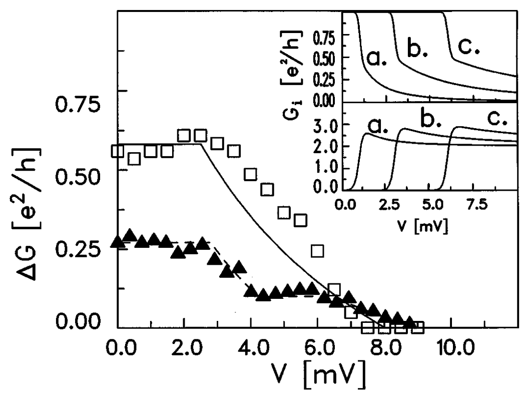

FIG. 1. The squares give $\Delta G(V)$ for Fig. 2, curve 3 of [1] and the triangles give the noise amplitude multiplied by 2 (for visibility) of Fig. 4, curve 1 of [1] (uncertainties $\sim 0.1 e^2/h$). VZ's theory gives (a) the solid curve for $\Delta G(V)$ for $i = 1$, with $E_1, E_1' = 8, 3$ meV, $\alpha_1 = 1$ and a Kondo temperature $T_K^1 = 17$ K; and (b) the dashed curve for $i = 1, 2$, with $E_{1,2} = 9, 4.2$ meV, $E_{1,2}' = 6.2, 2.8$ meV, $\alpha_{1,2} = 1, 0.8$, and $T_K^{1,2} = 8.9, 6.2$ K. The upper (lower) inset shows KK's [2] (Kozub's [6]) predictions for $G_i(V)$ for elastic (inelastic) scattering, for $E_i = 1, 3, 6$ meV (a, b, c), at $T = 1.2$ K.

In VZ's scaling theory [3], the renormalized (energy-dependent) dimensionless TLS-electron couplings become isotropic near the Kondo temperature T_K^i [3], $v_i^{x,y,z} = v_i(\varepsilon)$, and can be obtained to leading logarithmic order by solving the scaling equations (4.5) of Ref. [3(b)]; since E_i provides a lower cutoff for the scaling procedure, $v_i(\varepsilon < E_i) \simeq v_i(E_i)$. Since the corresponding scattering cross section $\sigma_i(\varepsilon)$ is proportional [3(c)] to $k_F^{-2} v_i^2(\varepsilon)$, we estimate the ZBA contribution of TLS "i" as [2] $G_i(V, E_i) \simeq -\alpha_i \frac{2e^2}{h} v_i^2(eV)/v_{\mathrm{fp}}^2$, where $\alpha_i \simeq 1$ is a geometry-dependent constant [5], and we normalized G_i by the fixed point coupling v_{fp} to recover the unitarity limit $2e^2/h$ [4,5] at $V = 0$ if $E_i = 0$. Thus each fast TLS is characterized by four parameters $(\alpha_i, E_i, E_i', T_K^i)$, and $\Delta G(V) = |\sum_i G_i(V, E_i) - G_i(V, E_i')|$. Figure 1 shows that the data for two samples of Ref. [1] can be fitted quite well using (a) one and (b) two TLSs, respectively.

In contrast, the inset in Fig. 1 shows KK's [2] prediction for $G_i(V)$ for elastic scattering, and also Kozub's [6] for inelastic scattering. Inspection shows that due to these $G_i(V)$ curves' long (power-law) tails, it is impossible to fit $\Delta G(V)$ using the difference $|G_i - G_i'|$ (nor using a sum $|\sum_i (G_i - G_i')|$ for several TLSs): $E_i \ll E_i'$ gives too long a tail, and $E_i \simeq E_i'$ too small a height for $\Delta G(0)$, even though, to obtain a maximally large $G_i(0) \simeq e^2/h$, we took the TLS in the junction center (KK's $q = 0.5$) and assumed extremely large effective cross sections ($\simeq k_F^{-2}$).

In summary, KSK's experiments for the first time allow the measurements of the conductance contributions of *individual* fast TLSs; the $\Delta G(V)$ curves agree much better with VZ's than KK's theory. If both the V and T dependence of ΔG were known, a V/T scaling analysis [4,5] could provide a further test for VZ's scenario.

We thank KSK for discussions and for sending us their data. G. Z. was supported by the Magyary Scholarship and OTKA T021228, OTKA TO 24005/1997, and F016604, and J. v. D. by "SFB 195" of the DFG.

G. Zaránd,[1] Jan von Delft,[2] and A. Zawadowski[1]
[1]Institute of Physics, Technical University of Budapest
H 1521 Budafoki út 8., Budapest, Hungary
[2]Institut für Theoretische Festkörperphysik
Universität Karlsruhe, 76128, Karlsruhe, Germany

Received 23 May 1997 [S0031-9007(97)05146-6]
PACS numbers: 72.15.Qm, 71.23.Cq, 72.10.Fk, 73.40.Jn

[1] R. J. P. Keijsers, O. I. Shklyarevskii, and H. van Kempen, Phys. Rev. Lett. **77**, 3411 (1996).
[2] V. I. Kozub and I. O. Kulik, Zh. Eksp. Teor. Fiz. **91**, 2243 (1986) [Sov. Phys. JETP **64**, 1332 (1986)].
[3] (a) K. Vladár and A. Zawadowski, Phys. Rev. B **28**, 1564 (1983); (b) **28**, 1582 (1983); (c) **28**, 1596 (1983).
[4] D. C. Ralph *et al.,* Phys. Rev. Lett. **72**, 1064 (1994).
[5] J. von Delft *et al.,* Ann. Phys. **263**, 1 (1998).
[6] V. I. Kozub, Fiz. Tverd. Tela (Leningrad) **26**, 1995 (1984) [Sov. Phys. Solid State **26**, 1186 (1984)].

0031-9007/98/80(6)/1353(1)$15.00